卢瑟福模型:

原子尺度: $1\text{Å} = 0.1\,nm$

原子核尺度: $1\,fm$

$1\,eV = 1.6\times10^{-19}\,J$

原子物理: eV
核物理: MeV
粒子物理: GeV or TeV

$F = eN_A = 96500\,C/mol$

$\sigma = \pi d^2$ 散射截面.

平均自由程: $V\cdot n = L\cdot\sigma\cdot n = 1$ (分子数密度)

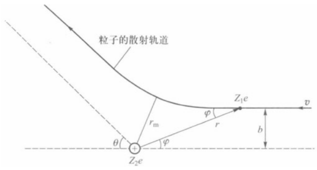
$\Rightarrow L = \frac{1}{\sigma\cdot n}$

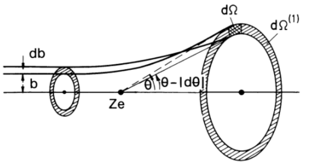
气体中, 分子间存在考虑相对速度 $v_{rel} = \sqrt{2}v$

$\Rightarrow L = \frac{1}{\sqrt{2}n\sigma}$

引入气体/液体密度系数 $\epsilon = \frac{\rho_{gas}}{\rho_{liquid}} = \frac{n_{gas}}{n_{liquid}} \approx \frac{n}{1/d^3}$

$\Rightarrow n \approx \frac{\epsilon}{d^3} \Rightarrow d = \sqrt{2}\pi\epsilon L$.





库伦散射公式: $b = \frac{a}{2}\cot\frac{\theta}{2}$, 其中 $a = \frac{Z_1Z_2e^2}{4\pi\epsilon_0 E}$, E为入射粒子动能. $\tan\frac{\theta}{2} = \frac{u_{t=+\infty}}{E}$

由 $\vec{F} = \frac{1}{4\pi\epsilon_0}\frac{Z_1Z_2e^2}{r^2}\hat{e}_r = \frac{k}{r^2}\hat{e}_r \Rightarrow F_L = \frac{k}{r^2}\sin\varphi = m\frac{dv_L}{dt}$ $\Rightarrow m\frac{dv_L}{dt} = \frac{k}{v_0 b}\frac{d\varphi}{dt}\sin\varphi$ $\quad u = \frac{1}{4\pi\epsilon_0}\frac{Z_1Z_2}{r}$

动量守恒: $mv_0\cdot b = mwr^2 = mr^2\frac{d\varphi}{dt} \Rightarrow \frac{1}{r^2} = \frac{1}{v_0 b}\frac{d\varphi}{dt}$ $\quad\Rightarrow \int_0^{v_0\sin\theta} dv_L = \frac{k}{mv_0 b}\int_0^{\pi-\theta}\sin\varphi d\varphi$

修正: ① E是考虑质心系动能: $E_c = \frac{M}{m+M}E_L = \frac{1}{2}\mu v_{rel}^2$

卢瑟福公式: $\sigma_c(\theta) = \left(\frac{1}{4\pi\epsilon_0}\frac{Z_1Z_2e^2}{4E}\right)^2\frac{1}{\sin^4\frac{\theta}{2}}$

由 $d\sigma = 2\pi b\,db = 2\pi\left(\frac{a}{2}\cot\frac{\theta}{2}\right)\left(-\frac{a}{2}\csc^2\frac{\theta}{2}\cdot\frac{1}{2}d\theta\right)$

$= -\frac{2\pi a^2}{4}\frac{\cos\frac{\theta}{2}}{\sin^3\frac{\theta}{2}}d\theta = -\frac{\pi a^2}{8}\frac{\sin\theta d\theta}{\sin^4\frac{\theta}{2}} = -\frac{a^2}{16}\frac{d\Omega^{(1)}}{\sin^4\frac{\theta}{2}}$

$\Rightarrow \left|\frac{d\sigma}{d\Omega}\right| = +\frac{a^2}{16}\frac{1}{\sin^4\frac{\theta}{2}} = \left(\frac{1}{4\pi\epsilon_0}\frac{Z_1Z_2e^2}{4E}\right)^2\frac{1}{\sin^4\frac{\theta}{2}}$

微分散射截面. 表示单位立体角dΩ内散射到某一指定角度θ的概率密度.

dσ 是一个原子核的有效散射截面.

有效截面总面积: $dS = n\cdot D\cdot S\,d\sigma$

⇒ 一个α粒子被散射到dΩ内的概率

$P(d\Omega) = \int\frac{dS}{S} = \int nD\,d\sigma = nD\int\frac{d\sigma}{d\Omega}d\Omega$

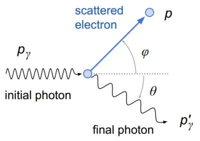
$\Rightarrow N(d\Omega) = N_0\cdot P(d\Omega)$

普朗克公式: $u(\nu,T) = \frac{8\pi h\nu^3}{c^3}\frac{1}{e^{h\nu/kT}-1}$

$u(T) = \int_0^\infty d\nu\,u(\nu,T) = \frac{8\pi^5k^4}{15c^3h^3}\cdot T^4 = A\cdot T^4$

$J = \sigma T^4$, $\sigma = \frac{c}{4}A$.

光电效应: $h\nu - W_0 = E_k = eV_0$
逸出功 截止电压



康普顿散射: $\Delta\lambda = \lambda_c(1-\cos\theta)$

$\lambda_c = \frac{h}{mc} = 2.4\,pm$

光子与原子外层近自由电子作用.

与其他粒子, 有 $\lambda_c(atom) = \frac{h}{Mc}$

能量守恒: $P_rc + E_0 = P'_rc + E$

$\Rightarrow (P_r - P'_r)c + mc^2 = \sqrt{m^2c^4 + p^2c^2}$

动量守恒: $P_r = P'_r\cos\theta + p\cos\phi$

$P'_r\sin\theta = p\sin\phi$

$\Rightarrow \Delta\lambda = h\left(\frac{1}{P'_r} - \frac{1}{P_r}\right) = \frac{h}{mc}(1-\cos\theta)$

自由电子不能完全吸收或放出光子.

Bohr's model.

H光谱: $\frac{1}{\lambda} = R_H\left(\frac{1}{n^2} - \frac{1}{n'^2}\right)$

$R_H = 109677\,cm^{-1}$

n=1. 紫外区 莱曼系
n=2. 紫外+可见 巴耳末系
n=3. 红外区, 帕邢系
n=4. ~ , 布拉开系
n=5 普丰德系

假设1: 角动量量子化: $|\vec{L}| = mv_nr_n = n\hbar$, n=1.2.3...

假设2: $h\nu_{nn'} = E_n - E_{n'}$

考虑其做圆周运动: $\frac{mv_n^2}{r_n} = \frac{1}{4\pi\epsilon_0}\frac{Ze^2}{r_n^2}$

$\Rightarrow r_n = \frac{n^2}{Z}\frac{4\pi\epsilon_0\hbar^2}{me^2} = \frac{n^2}{Z}\cdot a_B$

$v_n = \frac{Z}{n}\frac{e^2}{4\pi\epsilon_0\hbar c}\cdot c = \frac{Z}{n}\cdot\alpha\cdot c$

周期: $T = \frac{2\pi r_n}{v_n} = \frac{2\pi a_B}{\alpha c}\cdot\frac{n^3}{Z^2} = T_1\cdot\frac{n^3}{Z^2}$

$a_B = 0.053\,nm$. $\alpha = \frac{1}{137}$ $\quad T_1 = 10^{-16}s$

Compton wavelength: $\lambda_C = \frac{h}{mc}$

$\Rightarrow \lambda_c = 2\pi\cdot\alpha\cdot a_B$

H中: 电子的能量:

$E_n = \frac{1}{2}mv_n^2 - \frac{1}{4\pi\epsilon_0}\frac{e^2}{r_n} = -\frac{1}{n^2}\frac{mc^2\alpha^2}{2}$

注意到, $E = K + U = -K$. virial theorem

$E_1 = -13.6\,eV$

Rydberg constant: $R_\infty = \frac{|E_1|}{hc} = \frac{mc^2\alpha^2}{4\pi\hbar c}$ (未考虑原子核运动 m为电子的质量)

$\bar{\lambda}_c = \frac{\lambda_c}{2\pi} = \frac{\hbar}{mc} = 0.39\,pm$

$a_B = 4\pi\epsilon_0\frac{\hbar^2}{me^2} \approx 53\,pm$

$r_e = \frac{1}{4\pi\epsilon_0}\frac{e^2}{mc^2} = \alpha^2 a_B \approx 2.8\,fm$

$\Lambda = \frac{\bar{\lambda}_c}{\alpha^2} = \frac{hc}{mc^2\alpha^2} = \frac{1}{4\pi R_H} = \frac{\lambda_{min}}{4\pi} \approx 7.2\,nm$

r_e. 电子经典半径

$4\pi\Lambda$: 光子所能发出的最短波长

相对论修正: $E_k = \sqrt{m^2c^4 + p^2c^2} - mc^2$

$\approx \frac{p^2}{2m} - \frac{p^4}{8m^3c^2}$

相对论. 电子自旋导致了 fine structure.
破坏了l的简并性.

Bohr-Sommerfeld model:

假设轨道为椭圆

n.l 共同描述电子轨道.

n
l ~ 0 ~ n-1
m_l ~ -l, -l+1, ..., l+1
$m_s = \pm\frac{1}{2}$

由于电子屏蔽, $n \to n_{eff} = n - \Delta_l$

$\Rightarrow E_n = -\frac{Rhc}{(n-\Delta_l)^2}$

Rydberg atom: $n \gg 1$.

可用 Bohr's model 解释.

$r \propto n^2$

寿命 $\tau \propto n^{4.5}$

外层电子结合能 $E \propto \frac{1}{n^2}$.

Frank-Hertz 实验:

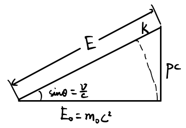
$E(Hg) = 4.9\,eV$

证明能级分立.

Wave-Particle duality:

λ≫D: Wave
λ≪D: particle

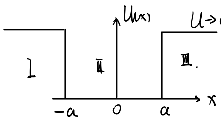
D主要描述与光作用的物体的尺度.



例. 电子, 光子都有 λ=4nm

$\frac{P_e}{P_r} = \frac{h/\lambda}{h/\lambda} = 1$

$\frac{K_e}{K_r} = \frac{\sqrt{(mc^2)^2 + (P_ec)^2} - mc^2}{P_rc}$



- 一维无限深方势阱: $U(x) = \begin{cases}0, & |x|<a\\ \infty, & |x|\ge a\end{cases}$

I. III: $\frac{d^2\psi}{dx^2} + \frac{2m}{\hbar^2}(E-\infty)\psi = 0 \Rightarrow \psi = 0$

II: $\frac{d^2\psi}{dx^2} + \frac{2m}{\hbar^2}(E-0)\psi = 0$ $\quad$ 令 $k = \frac{\sqrt{2mE}}{\hbar}$

$\Rightarrow \frac{d^2\psi}{dx^2} + k^2\psi = 0 \Rightarrow \psi = A\cos kx + B\sin kx$, $|x|<a$

边界条件: 连续性 边界连续: $\psi(a) = A\cos ka + B\sin ka = 0$
$\psi(-a) = A\cos ka - B\sin ka = 0$
$k_n = \frac{n\pi}{2a}$
$E_n = \frac{\hbar^2\pi^2}{8ma^2}n^2$

解析连续: 只有无限高的时候才满足.

$\psi_n = A_n\sin\frac{n\pi}{2a}(x+a)$, $|x|<a$
$\psi_n = 0$, $|x|\ge a$

归一化条件: $\int_{-a}^{a}A_n^2\sin^2\frac{n\pi}{2a}(x+a)dx = 1 \Rightarrow A_n = \frac{1}{\sqrt{a}}$

量子力学导论:

$E = \hbar\omega = h\nu$

$\vec{p} = \hbar\vec{k}$, $p = \frac{h}{\lambda}$

$\Psi \propto e^{\left(-i\frac{Et}{\hbar} + i\frac{\vec{p}\cdot\vec{r}}{\hbar}\right)}$

引入驻波条件:

$pr = \hbar kr = \hbar\frac{2\pi}{\lambda}r = n\hbar$

$\Rightarrow 2\pi r = n\lambda$

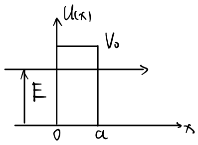
Schrödinger equation:

含时: $i\hbar\frac{\partial\Psi(\vec{r},t)}{\partial t} = \left[-\frac{\hbar^2}{2m}\nabla^2\Psi + V(\vec{r})\right]\Psi$

定态: $\left(-\frac{\hbar^2}{2m}\nabla^2 + V\right)\psi = E\psi$

$\oint|\Psi(\vec{x},t)|^2 d\vec{x}\,dt = 1$

$\Delta x\cdot\Delta p \ge \frac{\hbar}{2}$, $\Delta E\cdot\Delta t \ge \frac{\hbar}{2}$



势垒: $U(x) = \begin{cases}0, & x<0, x>a\\ V_0>0, & 0<x<a\end{cases}$

记 $k_1^2 = \frac{2mE}{\hbar^2}$, $k_2^2 = \frac{2m(V_0-E)}{\hbar^2}$

$\frac{d^2\psi_1}{dx^2} + \frac{2mE}{\hbar^2}\psi_1 = 0$, $x<0$
$\frac{d^2\psi_2}{dx^2} + \frac{2m(E-V_0)}{\hbar^2}\psi_2 = 0$. $0<x<a$
$\frac{d^2\psi_3}{dx^2} + \frac{2mE}{\hbar^2}\psi_3 = 0$, $x>a$.

$\Rightarrow \begin{cases}\frac{d^2\psi_1}{dx^2} + k_1^2\psi_1 = 0\\ \frac{d^2\psi_2}{dx^2} - k_2^2\psi_2 = 0\\ \frac{d^2\psi_3}{dx^2} + k_1^2\psi_3 = 0\end{cases}$ $\Rightarrow \begin{cases}\psi_1 = Ae^{ik_1x} + A'e^{-ik_1x}\\ \psi_2 = Be^{k_2x} + B'e^{-k_2x}\\ \psi_3 = Ce^{ik_1x} + (C'e^{-ik_1x})\end{cases}$

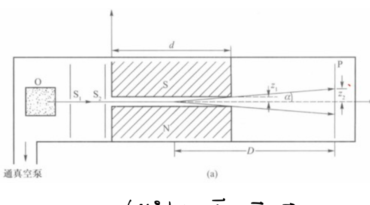
C'=0, 因为区域III中波不往回走.

边界条件: x=0: $\psi_1(0) = \psi_2(0) \Rightarrow A + A' = B + B'$
$\psi'_1(0) = \psi'_2(0) \Rightarrow ik_1A - ik_1A' = k_2B - k_2B'$
x=a: $\psi_2(a) = \psi_3(a) \Rightarrow Be^{k_2a} + B'e^{-k_2a} = Ce^{ik_1a}$
$\psi'_2(a) = \psi'_3(a) \Rightarrow k_2Be^{k_2a} - k_2B'e^{k_2a} = ik_1Ce^{ik_1a}$

$\Rightarrow C' = \frac{-4ik_1k_2e^{-ik_1a}}{(k_1+ik_2)^2e^{k_2a} - (k_1-ik_2)^2e^{-k_2a}}A$ 透射波

$A' = \frac{(k_1^2+k_2^2)(e^{-k_2a} - e^{k_2a})}{(k_2-ik_1)^2e^{k_2a} - (k_2+ik_1)^2e^{-k_2a}}A$ 反射波.

精细结构:



$\vec{\mu}_L = -\frac{e}{2m}\vec{L}$

$\mu_{Lz} = -\frac{e}{2m}m_l\hbar$

$= -m_l\mu_B$.

$S = \sqrt{s(s+1)}\hbar$ $\quad\vec{\mu}_S = -\frac{e}{m}\vec{S}$

$m_s = \pm\frac{1}{2}$ $\quad\mu_{Sz} = m_s\mu_B$

$\vec{F} = \vec{\mu}\cdot\nabla\vec{B}$ $\Rightarrow \begin{cases}x = vt\\ z = \frac{1}{2}\frac{F_z}{m}t^2\end{cases}$

$\Rightarrow F_z = \mu_z\frac{\partial B_z}{\partial z}$

$\alpha = \arctan\left(\frac{dz}{dx}\right) = \arctan\left(\frac{F_zt}{mv}\right) = \arctan\left(\frac{F_zd}{mv^2}\right)$

$z_2 = D\tan\alpha$

$\Rightarrow z_2 = \mu_z\cdot\frac{\partial B_z}{\partial z}\cdot\frac{d\cdot D}{mv^2} = \mu_z\left(\frac{\partial B_z}{\partial z}\frac{dD}{3kT}\right)$

$\mu_z = m_jg_j\mu_B$

角动量加法: $\vec{L}_t = \vec{L}_1 + \vec{L}_2$

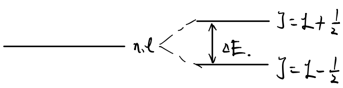
$|\vec{L}_t|$ 取值为 $||\vec{L}_1| - |\vec{L}_2|| \sim |\vec{L}_1| + |\vec{L}_2|$

间隔为1.

$\vec{J} = \vec{L} + \vec{S}$, $|l-s| \le j \le l+s$. $m_j = m_l + m_s$

$\mu_z = m_jg_j\mu_B$. $\quad g_j = \frac{3}{2} + \frac{1}{2}\frac{S^2 - L^2}{J^2}$

主线系: nP→2S
锐线系: nS→2P
漫线系: nD→2P
基线系: nF→3D



轨道角动量和自旋角动量耦合作用:

电子静止参考系下: $i = \frac{ev_n}{2\pi r_n} = \frac{emv_nr_n}{2\pi mr_n^2} = \frac{en\hbar}{2\pi mr_n^2}$

$\vec{B}_l = \frac{\mu_0}{4\pi}\oint\frac{Id\vec{l}\times\vec{r}}{r^3} = \frac{\mu_0 i}{4\pi}\cdot\frac{2\pi r\cdot r}{r^3}\hat{z} = \frac{\mu_0 i}{2r}\hat{z} = \frac{\mu_0 e}{4\pi mr^3}\vec{L}$

$U_s = -\vec{\mu}_s\cdot\vec{B}_l = -\frac{e}{m}\vec{S}\cdot\frac{\mu_0 e}{4\pi mr^3}\vec{L} = -\frac{\mu_0 e^2}{4\pi m^2r^3}\vec{S}\cdot\vec{L}$

$\vec{S}\cdot\vec{L} = \frac{J^2 - L^2 - S^2}{2} = \frac{\hbar^2}{2}[j(j+1) - l(l+1) - s(s+1)]$

对单电子, $j = l \pm \frac{1}{2}$

$\Rightarrow \vec{S}\cdot\vec{L} = \begin{cases}\frac{1}{2}l\hbar^2, & j = l+\frac{1}{2}\\ -\frac{1}{2}(l+1)\hbar^2, & j = l-\frac{1}{2}\end{cases}$

钠双黄线: $3^2P_{3/2} \to 3^2S_{1/2}$ 589.0 nm

$3^2P_{1/2} \to 3^2S_{1/2}$ 589.6 nm

Zeeman Splitting (Weak)

加入外场B, $\Delta E = -\vec{\mu}\cdot\vec{B} = -m_jg_j\mu_BB$

normal ~: $\vec{S} = 0$, $\vec{J} = \vec{L}$

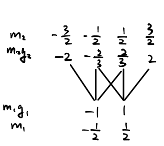
跃迁选择定则: $\Delta m_j = 0, \pm1$

例: $^2P_{3/2} \to {}^2S_{1/2}$

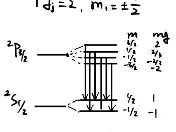
$^2P_{3/2}$: $\begin{cases}S = \frac{1}{2}, l = 1, j = \frac{3}{2}\\ g_j = \frac{4}{3}, m_z = \pm\frac{1}{2}, \pm\frac{3}{2}\end{cases}$

$^2S_{1/2}$: $\begin{cases}S = \frac{1}{2}, l = 0, j = \frac{1}{2}\\ g_j = 2, m_1 = \pm\frac{1}{2}\end{cases}$

$m_2 - m_1 = 1$, σ^+ 左旋
$m_2 - m_1 = 0$, π 线偏
$m_2 - m_1 = -1$, σ^- 右旋



6条谱线



$\Delta mg = \pm\frac{1}{3}, \pm1, \pm\frac{5}{3}$.

6条谱线.

Stark effect:

电子相对于原子核的平均分布不再与原点重合

电偶极矩 $\vec{D} = -e\sum\vec{r}_i$

$U = -\vec{D}\cdot\vec{E}$

谐振子势: $E_n = (n+\frac{1}{2})\hbar\omega$, n=0, 1, ...

$\psi_n = N_nH_n(\alpha x)e^{-\frac{1}{2}\alpha^2x^2}$, $\quad N_n = \sqrt{\frac{\alpha}{\sqrt{\pi}2^nn!}}$, $\alpha = \sqrt{\frac{m\omega}{\hbar}}$

$H_n(\xi) = (-1)^ne^{\xi^2}\frac{d^n}{d\xi^n}e^{-\xi^2}$

库伦势: $\psi_{nlm} = R_{nl}(r)\cdot P_{lm}(\theta)F_m(\phi)$

n = 1, 2, 3 ...
l = 0, 1, ..., n-1
m = -l, -l+1 ..., l.

氢原子, 类氢离子.
其能级E_n只与n有关.
关于l是简并的.
这是库伦势的性质.

$P(r,\theta,\phi) = |\psi_{nlm}|^2r^2\sin\theta\,dr\,d\theta\,d\phi$

$R_{10} = 2a^{-\frac{3}{2}}e^{-r/a}$

强磁场下，帕邢-巴克效应。

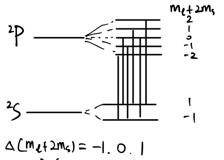
$\Delta E = (2m_s + m_\ell)\mu_B B$

跃迁选择定则：$\begin{cases}\Delta m_s = 0\\ \Delta m_\ell = 0, \pm1\end{cases}$

例：$\begin{matrix}S=\frac12\\ \ell=1\end{matrix}\ {}^2P \longrightarrow {}^2S\ \begin{matrix}S=\frac12\\ \ell=0\end{matrix}$

$m_\ell+2m_s$	-2	0	-1	1	0	+2
m_ℓ	-1		0		1	
m_s	$-\frac12$	$\frac12$	$-\frac12$	$\frac12$	$-\frac12$	$\frac12$

m_{s_1}: $-\frac12$, $\frac12$; m_{ℓ_1}: 0; $m_{\ell_1}+2m_{s_1}$: -1, 1



$\Delta(m_\ell + 2m_s) = -1, 0, 1$

3条谱线，6种跃迁。

电子-核角动量叠加：I.

$\vec F = \vec I + \vec J$

$\mu = m_F g_F \mu_B$，$g_F = g_J \dfrac{F(F+1)+J(J+1)-I(I+1)}{2F(F+1)}$

例 ^6Li：基态为 $1s^2 2s^1$，考虑 2s 的分裂。

$I_N = 1$，$\ell = 0$，$S = \frac12 \Rightarrow F = \frac12$ 或 $\frac32$

$m_F = \pm\frac12$ 或 $\pm\frac12, \pm\frac32$

多电子原子。

电子组态：$(n, \ell, m_\ell, s, m_s)$，$n\ell^{\#e}$，$\#e \le 2(2\ell+1)$

原子态：$(n, \ell, m_\ell, s, m_s, j, m_j, I, m_I, F, m_F)$，$n^{2S+1}\ell_j$

Pauli 不相容原理：每个电子不能处在相同的状态。

$L+S$ = 偶数

洪特定则：① S↑，E↓

② S一定时，L↑，E↓

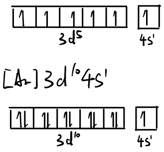
③ S, L一定，

1°. 轨道<半满，J↓，E↓

2°. 轨道>半满，J↑，E↓

$_{24}Cr$：$[Ar]3d^5 4s^1$

$_{29}Cu$：$[Ar]3d^{10}4s^1$



L-S 和 j-j 耦合。

$\delta(\ell_i s_i)$，$\varphi(\ell_i s_i)$

$G_1(S_1 S_2)$ $G_2(\ell_1 \ell_2)$ $G_3(\ell_1 S_1)$ $G_4(\ell_2 S_2)$ $G_5(\ell_1 S_2)$ $G_6(\ell_2 S_1)$ weak

S_{12}, L_{12} → J_{12}：L-S 耦合。

j_1, j_2 → J_{12}：j-j 耦合。

$\hat H = \hat H_0 + G_{LS}\vec L\cdot\vec S + G_{jj}\vec j_1\cdot\vec j_2$

$G_{LS} \gg G_{jj}$：质子较轻，处于低激发态的原子。

$G_{LS} \ll G_{jj}$：质子较重，处于高激发态的原子。

跃迁定则：

① L-S：$\begin{cases}\Delta S = 0\\ \Delta L = 0, \pm1\\ \Delta J = 0, \pm1\ (J=0 \to J'=0 \text{除外})\end{cases}$

② j-j：$\begin{cases}\Delta j = 0, \pm1\\ \Delta J = 0, \pm1\\ (J=0 \to J'=0 \text{除外})\end{cases}$

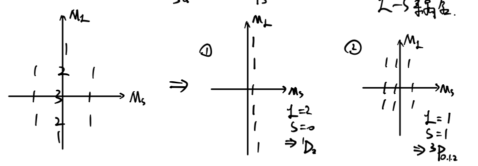
例：$2p^1 3p^1$ 的 L-S 耦合。

S	L	J	原子态
0	0 1 2	0 1 2	$^1S_0$ $^1P_1$ $^1D_2$
1	0 1 2	1 0, 1, 2 1, 2, 3	$^3S_1$ $^3P_{0,1,2}$ $^3D_{1,2,3}$

基态：$^3D_1$

$2p^2$ 的 L-S 耦合。Slater：

M_L \ M_S	-1	0	1
+2		(1,+)(1,-)	
+1	(1,-)(0,-)	(1,+)(0,-) (1,-)(0,+)	(1,+)(0,+)
0	(1,-)(-1,-)	(1,+)(-1,-) (0,+)(0,-) (1,-)(-1,+)	(1,+)(-1,+)
-1	(0,-)(-1,-)	(0,+)(-1,-) (0,-)(-1,+)	(0,+)(-1,+)
-2		(-1,+)(-1,-)	



① $L=2$，$S=0$ ⇒ $^1D_2$

② $L=1$，$S=1$ ⇒ $^3P_{0,1,2}$

③ $L=0$，$S=0$ ⇒ $^1S_0$

偶数定则：$L+S$ = 偶

$2p^2$：

① $S=0$，$L=0$：$^1S_0$

② $S=0$，$L=2$：$^1D_2$

③ $S=1$，$L=1$：$^3P_{0,1,2}$

基态：$^3P_0$

核物理：

^A_ZX $\begin{cases}A\text{：质量数：质子数+中子数}\\ Z\text{：质子数}\end{cases}$

电子、质子、中子自旋均为 $\frac12$。

$1u = 931.5\,MeV/c^2$

库伦散射公式：

$b = \dfrac{AB}{2k}\dfrac{e^2}{4\pi\varepsilon_0}\cot\dfrac{\theta}{2}$

A、B为入射粒子和靶核的核电荷数。

可通过核反应公式是否成立判断核的大小。

半衰期：$N = N_0 e^{-t/\lambda}$

$\lambda = \dfrac{\ln 2}{t_{half}}$，λ为衰变常数

Binding Energy：

$E_B = (Zm_p + Nm_n - m_A)c^2$ 原子核质量

$= (ZM_H + Nm_n - M_A)c^2$ 原子质量

四种基本力：

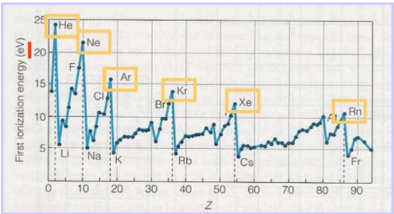
Force	Relative Strength	Range
Strong	1	~1 fm
Electromagnetic	$\sim10^{-2}$	Long: $\propto\frac{1}{r^2}$
Weak	$\sim10^{-6}$	$\sim10^{-3}$ fm
Gravitational	$\sim10^{-39}$	Long: $\propto\frac{1}{r^2}$

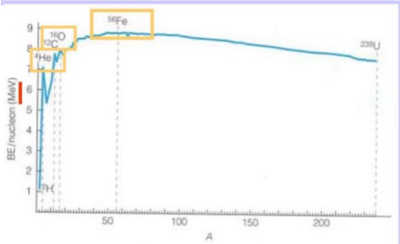
核半径公式：$r = A^{1/3}\cdot R_0$

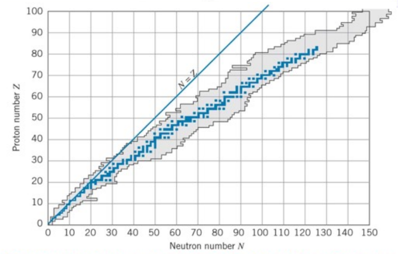
A为核子数，$R_0 = 1.2\,fm$

$\rho = \dfrac{Nm_n + Zm_p}{\frac43\pi r^3} \approx \dfrac{Au}{\frac43\pi R_0^3 A} \approx 2\times10^{14}\,g/cm^3$

核自旋：$\begin{cases}\text{偶偶核：自旋均为0}\\ \text{奇偶核：}\sim\text{为}\frac{\hbar}{2}\text{的半整数倍}\\ \text{奇奇核：}\sim\ \frac{\hbar}{2}\text{的整数倍}\end{cases}$ 基态。







Only nuclei with blue color are stable. Other Shadowing ones are radioactive nuclei.

α decay：$^A_ZX_N \to {}^{A-4}_{Z-2}Y_{N-2} + {}^4_2He_2$

$Q = (m_X - m_Y - m_{He})c^2$，$K_{He} = \dfrac{A-4}{A}Q$

$= [(M_X - Zm_e) - (M_Y - (Z-2)m_e) - (M_{He} - 2m_e)]c^2$

$= (M_X - M_Y - M_{He})c^2$

发生条件：$M_X(Z,A) > M_Y(Z-2, A-4) + M_{He}$

β^- decay：$^A_ZX \longrightarrow {}^A_{Z+1}Y + e^- + \bar\nu$

$Q = [m_X - (m_Y + m_e)]c^2$

$= (M_X - M_Y)c^2$

发生条件：$M_X(Z,A) > M_Y(Z+1, A)$

β^+ decay：$^A_ZX \to {}^A_{Z-1}Y + e^+ + \nu$

$Q = [m_X - (m_Y + m_e)]c^2$

$= [M_X - M_Y - 2m_e]c^2$

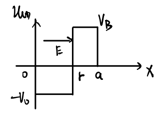
发生条件：$M_X(Z,A) > M_Y(Z-1, A) + 2m_e$

γ decay：α、β衰变后，子核处于激发态，其向低激发态跃迁后，放出γ光子。

EC：$^A_ZX + e_i^- \to {}^A_{Z-1}Y + \nu_e$

$Q = [m_X + m_e - m_Y]c^2 - W_i$

$= [M_X - M_Y]c^2 - W_i$



α decay 用 Schrodinger equation 描述。

$U(r) = \begin{cases}\infty, & x \le 0\\ -V_0, & 0 < x < r\\ V_B, & r \le x < a\\ 0, & r > a\end{cases}$

Q 方程：$i + T \to \ell + R$

$Q = K_\ell + K_R - K_i$（靶核静止，$K_T = 0$）

$= (1 + \dfrac{m_\ell}{m_R})K_\ell - (1 - \dfrac{m_i}{m_R})K_i - \dfrac{2\sqrt{m_i m_\ell K_i K_\ell}}{m_R}\cos\theta$

$K_\ell(\theta) = (u \pm \sqrt{u^2 + w})^2$ $\begin{cases}u = \dfrac{\sqrt{m_i m_\ell K_i}}{m_\ell + m_R}\cos\theta\\ w = \dfrac{m_R Q + K_i(m_R - m_i)}{m_\ell + m_R}\end{cases}$

放能反应，$Q > 0$，$u^2 + w > 0$ 恒成立。

吸能反应，$Q < 0$，$K_{阈} = -Q\dfrac{m_\ell + m_R}{m_\ell + m_R - m_i}$

考虑 $m_T \gg Q/c^2 \Rightarrow K_{阈} = -Q\dfrac{m_T + m_i}{m_T}$

$\mu_B = \dfrac{e\hbar}{2m} = 0.9274\times10^{-23}\,J\cdot T^{-1}$

$= 0.9274\times10^{-23}\,A\cdot m^2$

$= 0.009274\,mA\cdot nm^2$

$= 0.5788\times10^{-4}\,eV\cdot T^{-1}$

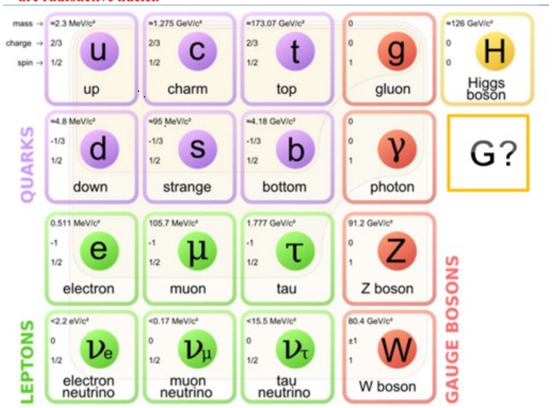
$m_e = 0.511\,MeV/c^2$

$m_p = 938.3\,MeV/c^2$

$m_n = 939.6\,MeV/c^2$

$hc = 1240\,eV\cdot nm$，$\hbar c = 197\,eV\cdot nm$

$\dfrac{e^2}{4\pi\varepsilon_0} = 1.440\,eV\cdot nm$



物质间交换光子发生电磁相互作用

夸克通过交换胶子发生强相互作用。

弱相互作用通过交换Z和W玻色子实现。

其主导β衰变和中微子相互作用

$\begin{cases}\text{Zero Mass} \to \text{Infinite Range}\\ \text{Finite Mass} \to \text{Finite Range}\end{cases}$

$\Delta E\cdot\Delta t \ge \frac{\hbar}{2}$

$\Delta E \propto mc^2$

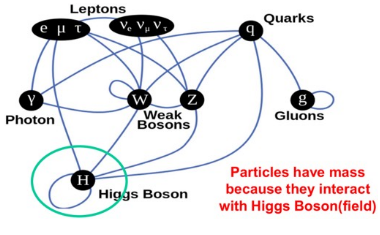
$\Delta t \ge \frac{\hbar}{2mc^2}$

$\Rightarrow \Delta x = c\Delta t \propto \dfrac{\hbar}{mc}$

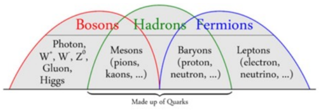
range $\propto \dfrac{\hbar}{c}\dfrac{1}{m}$

Numbers of Elementary Particles

	Types	Generations	Antiparticle	Colors	Total
Quarks	2	3	Pair	3	?
Leptons	2	3	Pair	None	?
Gluons	1	1	Own	8	?
W	1	1	Pair	None	2
Z	1	1	Own	None	?
Photon	1	1	Own	None	?
Higgs	1	1	Own	None	?
Total					?



Particles have mass because they interact with Higgs Boson(field)



Elementary particles vs Non-Elementary:
divided or undivided
1-1. Elementary bosonic particles: Gauge Bosons 规范玻色子 (photon...)
1-2. Elementary fermionic particles: Leptons 轻子 (electron...)
Quarks 夸克 (.....)

Non-elementary particles made by quarks: Hadrons 强子
2-1. mesons 介子 are bosonic hadrons (spin=even/2).
2-2. baryons 重子 are fermionic hadrons(spin=odd/2).